Small Orbital Planetary Lidar for Measurement of Water Vapor, Cloud and Aerosol Profiles

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Abstract: Active remote sensing measurments of the total water vapor column content are presented using a frequency tuned DBR laser (940 nm band) and a hard target return for a 0.4 Km open path.

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1. Introduction

The Martian atmosphere is surprisingly dynamic, with a highly variable water vapor distribution and an unusual amount of atmospheric dust and clouds [1]. The dynamics, and forcing functions of the many Martian atmospheric features, particularly the global processes involving water vapor, aerosol, ice distributions, and the planetary boundary layer (PBL) remain largely hypothesis [2]. To fully understand these processes will require global observations with a high temporal and spatial resolution which can only realistically be obtained from an orbiting Lidar.

We are conducting the critical R&D for a small, orbital, atmospheric lidar to measure water vapor and aerosol distributions from Mars orbit. Our lidar will profile the Mars' atmosphere during both day and night. Its measurements will have much higher vertical and spatial resolution than those to date or those planned. The lidar's water vapor global spatial resolution is approximately 1 degree and vertical resolution is ≤ km, and it appears that global maps of the vertical distribution of water vapor to four precipital microns (ppt.μm) during day and 0.8 ppt.μm during night could be made every 15 days. The lidar's aerosol measurements have 200 m resolution over the entire vertical column. Measurement of the backscatter depolarization will permit atmospheric ice and dust discrimination. The optical source will be a Master Oscillator Power Amplifier, MOPA, design using fiber amplifiers coupled with narow-linewidth single photon counting detectors. This combination of technology enables Differential Absorption Lidar (DIAL) to be practical for planetary missions for the first time.

2. Experimental

Our initial goal is to demonstrate a Mars Water Vapor Sounder (MWVS) that can determine the H_2O column content to better than one ppt.μm in both laboratory and atmospheric conditions and hence in the Martian atmosphere from orbit. The breadboard instrument is a simple direct transmission measurement made in the 940 nm water vapor band, where sources, absorption and photon counting detectors are available. The master oscillator is a DBR diode laser with an independently tunable, and electrically-isolated DBR. An array of Nd (neodymium)-doped optical-fiber-amplifier (NDFA) in parallel, with gain suppression at 1064 will provide the necessary optical power and supercedes an array of semiconductor optical amplifiers. The NDFAs are compact, low mass and have high electrical efficiency (>10%). For the results presented in this paper the power amplifiers were not used. A direct-detection very-narrow-linewidth, highly-sensitive, photon-counting receiver as developed for the ICESAT/GLAS mission will be used. However, for ease of use, Si-photodiodes are also used.

The current approach is to sweep the laser frequency across the absorption feature of interest and derive the salient parameters from a real-time fit to the absorption profile. Significant work has gone into developing the breadboard instrument, identifying candidate water vapor lines strong enough to provide high sensitivity to changes in H_2O amount, but are not as strong as to be saturated in the "wetter" spring conditions on Mars (~70ppt.μm water). Experimental absorption spectroscopy measurements are presented for both low-pressure, (Doppler broadened) and high pressure (collisional broadened) regimes. The same source and detectors are used to monitor transmission from three systems, a low-pressure 10 m optical cell, a 5m open-path in a controlled environment and a 0.4 Kilometer open-path atmospheric test range.

3. Results and Discussion

Initial test was to fill a low pressure cell with the equivalent moisture content of a column of the Martian atmosphere. (10 m path at ~5 mBarr). Figure 1 is a plot of the water Vapour Column Content expressed in precipital microns (ppt.µm) as a function of water vapour pressure. A 10 m optical cell is slowly filled with pure water vapour as the pressure, temperature and optical transmission are monitored. The plot shows two lines, the column content derived remotely from the transmission and the column content derived from the pressure and temperature using the Universal Gas law. A good fit is obtained using a gaussian fitting routine (Doppler broadened regime). However at pressures greater than about four hundred Pascals there is sufficient pressure broadening to cause the fitting routine to under estimate the column content. This is purely a function of the simple fitting routine which will be modified for a Doppler dominated Voigt profile.

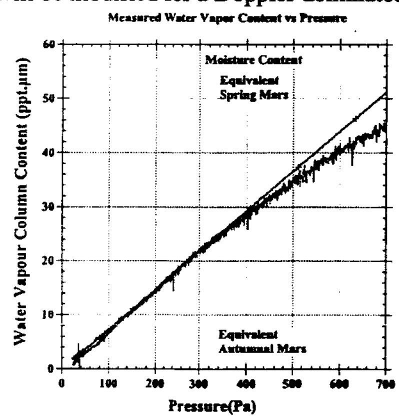

Fig. 1. Water content expressed in precipital microns (ppt.µm) as a function of pressure, measured optically at 934.193 nm through the 10m variable-path optical cell in pure water vapour. Also shown is the molecular concentration derived from the universal gas law for the ambient temperature of 23C°(Straight Line).

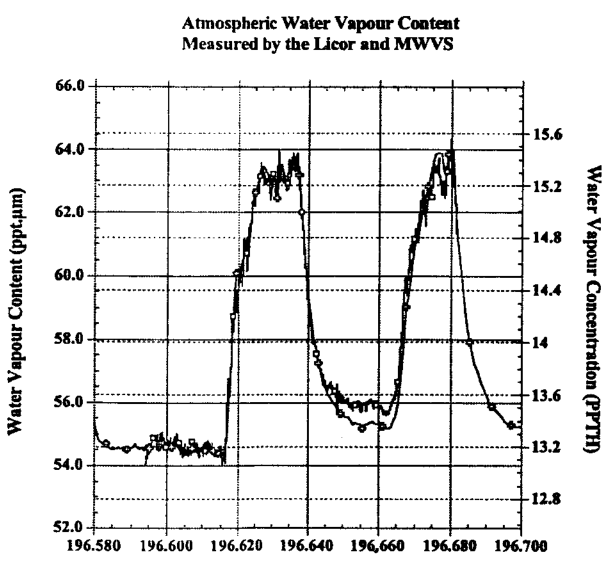

Fig. 2. Comparison of the MWVS (Open Sqrs) overlayed with a Licor (crosses) both measuring real-time changes over an open path. Licor data extends beyond the sounder

To help validate the approach the sounder was directly compared to a LICOR sampling the same volume at atmospheric pressure. Both the LICOR and sounder sample the same water column using the 5.15 m open path setup and the 934.193 nm line. The 5m column at atmospheric pressure (1022 mb) and 50% relative humidity gives approximately 50 ppt.μm of precipital water, equivalent to the total column content of the Martian atmosphere in Spring. The humidity was changed simply by running a dehumidifier. However at atmospheric pressure the absorption profile is pressure broadened and a Lorentzian fitting routine is used. As can be seen from the data, figure 2, there is excellent agreement between the sounder and LICOR. The sounder measuring to better than one precipital micron.

Remote sensing of the water vapor content over an a 0.42 Kilometer open path atmospheric test range using a retro-reflecting hard target were also performed. Plotted below are several scanned transmission profiles of the 933.97 nm line showing saturation on line center. Open-path atmospheric scans at 933.97nm over a 420 m horizontal path were made with less than 1 mW of launch power and at a scan rate of 1KHz. Scanning at less than 1KHz introduces atmospheric noise as the air can no longer considered stationary. The weather conditions were atrocious for the data in figure 3, heavy rain and winds gusting above 20 mph. These scans are typical single shots capture by the DAQ. There are several scans superimposed. Even though this line saturates under these conditions the fitting routine is still able to determine the absorption coefficient and FWHM for this path. The routine fits the whole line from a frquency dependent absorption coefficient and exponential absorption using a Levenberg Marquardt routine. BWI airport meteorological station reported air temp of 16C, dew point of 16C, and 96% relative humidity, heavy rain and wind during the time of these measurements. Data will also be presented showing long term correlation between the Licor and Sounder over the open path.

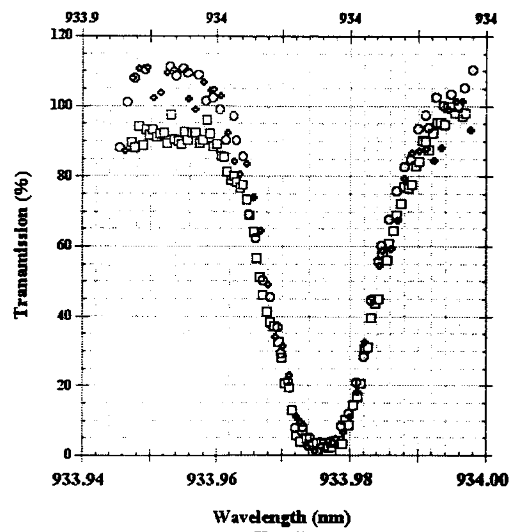

Fig. 3. Several wavelength scans of the 933.97 nm absorption, during heavy rain and over 96% RH, dewpoint 16°C over a 420 m open path. Under these conditions the transmission saturates but the fitting routine still works.

4. Discussion and Summary

We have shown a sounder capable of remotely measuring total water vapor content over a 0.4 Km open path to better than one ppt.μm with a cooperative hard target. While we have shown that the system can measure water vapor content to the desired precision the long-term absolute accuracy of the system must still ascertained. This test will have to include the optical amplifiers, uncooperative hard target, narrow filters and photon counting detectors. Our new NDFA based laser and electro-optic receiver technology is innovative and will enable a new class of small lidars for planetary atmospheric science investigations. With suitable wavelength laser-diode and fiber-amplifier components, our lidar approach can be generalized to measure other trace gases from orbit.

5. References

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